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BENCHMARKING OF WORLD CITIES THROUGH SELF-ORGANIZING MAPS

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Abstract

This paper takes for granted the structural urbanisation trend in our world. It argues that there is a global competition among world cities in different parts of our planet. It aims to map out the relative disparities among a preselected set of major global cities by offering a benchmark analysis of these cities on the basis of a recently completed comparative study on their socio-economic ‘power’. The analytical tool employed to highlight and better understand the relative position of these cities from a topological perspective is based on Self-Organizing Maps (SOMs). The empirical results are presented and interpreted from the perspective of a benchmark ranking of the various cities involved, while finally also an actor-oriented analysis of the various performance items of these cities is given.

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1. **Cities as Global Powerhouses?**[1]

Modern cities are powerhouses of creative thinking, development of new technologies, entrepreneurial spirit, socio-economic progress and ecologically sustainable transformation. A wealth of challenges and opportunities is found in urban environments, not only in the urban production and consumption domain, but also in the resource and infrastructure domain of these cities (see e.g. Black and Henderson, 2003; Duranton, 2007; Pumain and Moriconi-Ebrard, 1997). And over the past decades cities all over the world have managed to reinforce their socio-economic position, be it sometimes with up and downs.

It is noteworthy that the year 2007 meant an important milestone in the long record of urbanization in our world: for the first time in human history, the city took over the 'power' from its hinterland, since as of that year more than 50 percent of the world population was living in urban areas. The 21st century is by some people nowadays even called *'the urban century'*. Surprisingly, only a few centuries ago 20 percent of the population on our earth lived in cities. The structural urban development is still continuing, with urbanization rates exceeding 70 percent in various European countries and elsewhere (see for details e.g. Mega, 2010).

This long-term megatrend in population movement towards the city is the result of two underlying force fields, viz. the exponential growth in world population (with an average growth rate of approx. 1.2 percent per annum) and the rural-urban drift (due to the relatively more favourable socio-economic opportunities in urban agglomerations). In this context, it is foreseen by United Nations that until the year 2020, about 60 million people will move from sub-Saharan Africa to North-Africa and Europe. Both natural population growth and (domestic and foreign) migration will mean a formidable and unprecedented challenge to the resilience of urban systems in our world. And there is no reason to assume that the trend towards further urbanization will come to a standstill. It is even anticipated that in less than one generation time more than two-third of the population on our planet will live in urbanized areas. In Europe – but also in other regions of our world – the urbanization rate may have risen to 83 percent (557 million) by the year 2050 (European Commission, 2010). Non-urbanites will gradually become a minority.

The above sketched megatrend means clearly a dramatic transformation in settlement patterns in our world. This emerging re-positioning of cities may be interpreted as a *third* settlement revolution. The *first* revolution was essentially marked by a rural to urban shift in the past (instigated by safety and political motives), which led to the first demarcated cities (often with walls and fortifications) (see Tellier, 2009). A *second* revolution took place in the

[1] In this document, various concepts such as cities, urban areas, agglomerations etc. are used in a rather loose way. For a precise definition of all such concepts we refer to Gregory et al. (2009).

period of the Industrial Revolution (19th century) when large-scale industrialization and far-reaching labour specialisation led to the emergence of unprecedented scale advantages in large urban industrial agglomerations. And nowadays, we witness the rise of urban networks and mega-cities – comprising not only urban centres and suburban areas, but also edge cities, suburban areas, new towns and urban sprawl areas – that form altogether connected agglomerations (see also Castells, 1996). The trend towards global city networks is even increasingly imminent (see Sassen, 1991, 2010; Scott 2001).

In less than a century, the urban landscape in Europe has completely changed. Many current cities in Europe (Madrid, Lyon, Vienna, Paris, Torino, Stockholm, Frankfurt, Brussels of Amsterdam) were until the mid 1950s still relatively small. They turned into urban agglomerations with the rise of the Industrial Revolution, and continued to grow on a structural basis (despite various ups and downs). Clearly, urban sprawl meant at first glance a disruption of existing urbanization trends, but in the long run the central position of cities was even reinforced (Tellier, 2009). Metropolitan development nowadays increasingly turns into mega-cities development, and it appears to be hard to find a conclusive answer to Alonso's (1964) challenging question *"How big is big enough?"* and *"How big is too big?"*. It seems plausible that ongoing urban dynamics will remain a landmark in a modern open society in the future.

It is also noteworthy that modern urbanization means at the same time a disappearance of the strict border lines between urbanity and rurality (see also Vaz et al., 2006). While in the past centuries the city was clearly demarcated by city walls separating it from the hinterland, in modern centuries the morphology of cities has become diffuse (with urban village districts, suburbs, new towns, satellite cities and urban sprawl areas) and spatially segmented (see Musterd and Van Kempen, 2009).

This evolution did not only reflect a quantitative change in the share of inhabitants in urban areas in the national territory, but had also a qualitative impact of both a socio-economic and political nature. Modern network cities have turned into spearheads of (supra-)regional and (supra-)national power, not only from a socio-economic perspective (business, innovativeness, jobs, wealth), but also from a geo-political perspective (*'cities as global command and control centres';* see Sassen, 1991) and a technological perspective.

Consequently, modern urbanization does not only mean a shift from rurality to urbanity, but implies also the emergence of large-scale urban agglomerations which turn into mega-cities (see Nijkamp, 2010). Socio-demographic changes (e.g., ageing), migration and mobility, entrepreneurial dynamics, sustainability and efficiency of transport and energy systems, ICT (and other advanced technologies), and increasing returns to scale in urban agglomerations are the driving forces for new settlement patterns in our modern society. Cities have turned into force fields with both centripetal and centrifugal movements in an open world, an observation made already by Dematteis (1988). Especially the seminal work of Friedman (1986) on world city developments – leading to an urban system as an inter-connected global system with a specific hierarchical functional structure – has inspired much research on globalization and urban development (see also Beaverstock et al., 1999; Knox and McCarthy, 2005; Kourtit et al., 2011; McCann, 2008; Sassen, 2006).

Cities – often in the form of metropolitan areas – have increasingly run into a global race, in which monopolistic competition and product variety play a central role (see e.g. Abdel-Rahman and Fujita, 1990; Becker and Henderson, 2000; Duranton and Puga, 2000; Glaeser et al., 1992; Quigley, 1998). There are nowadays numerous attempts to rank the relative performance of cities in our world. The present study aims to test the relevance of a recently developed tool in computational neural network analysis, viz. Self-organizing Maps (SOMs), for ordering and ranking the relative positions of different world cities so as to better understand their performance in a global perspective.

The paper is organized as follows. The next section will exemplify some attempts to arrive at a relative comparative ranking of various cities world-wide. Then, Section 3 will be based on a concise description of the data base used in the present study, which originates from the Japanese Institute for Urban Strategies (2010). In a subsequent section, Section 4, we will concisely outline the mechanism and analytical power of SOMs, while the next sections, namely Sections 5-7, will offer the empirical findings followed by an interpretation. The concluding section will offer some retrospective and prospective remarks.

2. Urban Benchmarking

Cities and metropolitan areas in our world are to some extent operating like business firms in an open globalizing world, as they have to conquer a high share of international resources or revenues in order to reinforce their relative position. There have been many attempts to create a ranking system for major cities in our world in order to offer a systematic performance assessment of these cities. Such a ranking system has normally two objectives: (i) it provides to local stakeholders a comparative insight into the strong and weak points – relative to competitors– of the city at hand, and (ii) it offers evidence-based information for a tailor-made marketing policy of a given city (see also Cerreta et al., 2010).

From the numerous attempts to map out the relative strengths and weaknesses of a set of relevant cities we will only concisely address here a few empirical investigations. A major attempt can be found in comparative studies related to the concept of world cities (see Friedman, 1986; Sassen, 1991; Taylor, 2004; Taylor et al., 2011). In these studies the focus is on the position of cities from a global network perspective, in which proximity and connectivity plays a central role in identifying urban hierarchies on the basis of the links that advanced producer services share with the rest of the world. In this approach, the cities' position is not based on their nodal structure in a broader network, but on their contribution to shape the world city network. Especially advanced producer serves act as main agents for world city formation (see also GaWC, 2008). In later stages of the world city network, also linkage data from multinational firms were included in the statistical analysis. The resulting urban hierarchy in these studies is thus mainly dependent on the composition of the industrial sector, with a particular view on the advanced service sector.

Another comparative study on leading cities of the world and their competitive advantages was undertaken by Grosveld (2002). His statistical analysis of the strong and weak points of cities all over the world has been instigated by Porter's seminal book on 'The Competitive Advantages of Nations' (1990). This research aims to map out the key local factors that determine the international competitive position of cities in a globalizing world with the aim to arrive at a global ranking of cities. The data for the statistical review of these cities stem mainly from perceptions of decision-makers and experts in these cities. These perceptions are subdivided into integral and functional perceptions and are based on survey questionnaires. Based on an extensive statistical data base, the author was able to offer a raking of leading cities in the world.

Another, more recent study on the comparative performance of cities can be found in Caragliu et al. (2011). The authors aim to analyse urban performance from the perspective of infrastructural, human and social capital. They address in particular the class of so-called 'smart cities'. The statistical analysis of these cities is based on an extensive database from the Urban Audit data source, which comprises much information on demography, social aspects, economic impacts, training and education, environmental, culture and recreation. The authors aim to offer an exploratory underpinning for city rankings on the basis of a broad set of underlying city attributes (e.g., accessibility, public transport etc.). The authors combined also the city profiles with various functional urban criteria and were able to confirm various positive correlations between urban growth and underlying parametres.

An interesting study on the urban world, by mapping the economic power of cities, can also be found in a research publication of McKinsey Global Institute (2011). This research gives a ranking of the economic performance of 600 cities all over the world, based on their contribution to global economic wealth. It goes without saying that major metropolitan areas such as New York, London, Shanghai, Tokyo, Paris or Chicago assume top positions on this rank list.

Finally, we mention here the Global Power City Index (GPCI), created by the Institution for Urban Strategies (2010). This index evaluates and ranks the major cites of the world according to their comprehensive power to attract creative people and excellent companies from around the world amidst an environment of increasingly strong urban competition world-wide. This index comprises a multiplicity of important attributes and offers therefore a rather balanced picture of the economic performance and power of various world cities. We will employ the underlying database for a benchmark analysis of these cities and, consequently, this GPCI database will be discussed in slight greater detail in the next section.

3. The Database in our Study

This section describes the details of our database and the methodology employed. Our empirical approach is based on a unique data set from the Global Power City Index (GPCI), developed by the Institute for Urban Strategies at the Mori Memorial Foundation (2010) in Tokyo, covering two time periods. The GPCI-2010 evaluates the comprehensive power determinants of the 35 major cities' socio-economic power performance around the globe (e.g., New York Tokyo, Paris, Hong Kong) from the perspective of attracting talent, business and investment to cities. And provides a comprehensive ranking of the leading global cities based on 69 individual indicators of city' performance across multiple main dimensions that define today's global leading cities, namely 'Economy', 'Research & Development', 'Cultural Interaction', 'Livability', 'Ecology & Natural Environment', and 'Accessibility'. Each of these six main indicators was next subdivided into relevant and measurable sub-indicators, so that finally a strictly consistent and tested database on 69 sub-indicators for 35 world cities was created, for two period of time (2009 and 2010). Table 1 offers a concise overview of the main categories of performance indicators used in the GPCI-2010.

In highlighting the rankings of the individual indicators grouped in the six main categories used in the GPCI-2010, the index also demonstrates the different strengths of the socio-economic performance of the leading global cities. This information can also help to enhance the attractiveness of a particular city. Furthermore, GPCI -2010 also offers actor-specific scores and rankings of the cities socio-economic performance from the perspective of *Managers, Researchers, Artists, Visitors* and *Residents*, respectively, (who are active in stimulating the urban socio-economic activities in the global cities), so that a weighted average importance score for each city could be calculated.

Table 1: List of performance indicators of the GPCI-2010

FUNCTION	INDICATOR GROUP		INDICATOR
ECONOMY	Market attractiveness	1	*GDP*
		2	*GDP per capita*
		3	*GDP growth rate*
	Economic vitality	4	*Total market value of listed shares on stock exchanges*
		5	*Number of world's top 300 companies*
		6	*Number of employees*
	Business environment	7	*Unemployment rate*
		8	*Number of employees in service industry for enterpises*
		9	*Average wage level (compared to New York)*
		10	*Easiness of securing human resource*
		11	*Office area per employee*
	Regulations and risks	12	*Index of economic freedom*
		13	*Corporate tax rate*
		14	*Index of country risk (Political, economic, business, etc.)*
RESEARCH & DEVELOPM-ENT	Research background	15	*Number of researchers*
		16	*World's top 200 universities*
		17	*Basic skill of mathematics and science*
	Readiness for accepting and supporting researchers	18	*Readiness for accepting foreign researchers*
		19	*R&D expenditure*
	Achievement	20	*Number of registered industrial property rights (patents)*
		21	*Number of highly-reputed prize winner*
		22	*Activeness of interaction between reasearchers and outputs of their achievement*
CULTURAL INTERACTION	Trendsetting potential	23	*Trade value of Audiovisual and related services*
		24	*Number of holdings of international conventions*
		25	*Number of holdings of world-class largest cultural events*
		26	*Environment of creative activities*
	Accomodation environment	27	*Number of guest rooms of luxury hotels*
		28	*Number of hotels*
	Resource of attracting visitors	29	*Number of World Heritages (within 100km area)*
		30	*Cultural attractiveness, etc.*
		31	*Number of theaters and concert halls*
		32	*Number of major museums*
		33	*Number of stadium*
	Shopping & Dining	34	*Satisfactory level of shopping*
		35	*Satisfactory level of dining*
	Volume of interaction	36	*Number of Foreigners*
		37	*Number of visitors from abroad*
		38	*Number of foreign students*
LIVABILITY	Working environment	39	*Total working hours*
		40	*Satisfactory level of employees' life from the viewpoint of managers*
	Cost of living	41	*Average rent (residential)*
		42	*Average price level (compared to New York)*
	Security and safety	43	*Number of murder*
		44	*Vulnerability*
		45	*Healthy Life Expectancy*
		46	*Activeness of community*
	Life support functions	47	*Population density*
		48	*Number of medical doctors per residents*
		49	*Number of international schools per foreign residents*
		50	*Variety of retail shops*
		51	*Variety of restaurants*
ECOLOGY & NATURAL ENVIRONMENT	Ecology	52	*Number of companies with ISO 14001certification*
		53	*Percentage of renewable energy*
		54	*Percentage of recycling*
		55	*CO_2 emissions*
	Pollution degree	56	*Density of suspended particulate matter (SPM)*
		57	*Density of sulfur dioxide (SO_2)*
		58	*Density of nitrogen dioxide (NO_2)*
		59	*Water quality*
	Natural environment	60	*Situation of green coverage*
		61	*Average yearly temperature differences*
ACCESSIBI LITY	Infrastructure of transportation	62	*Travel time between inner-city areas and int'l airports*
		63	*Number of cities with international direct flights*
		64	*Number of travelers of international flights*
		65	*Number of runways*

	Infrastructure of inner-city transportation	66	*Number of stations (subway)*
		67	*Punctuality of public transportation (train, subway, bus)*
		68	*Satisfactory level of commuting*
		69	*Taxi fare*

All details can be found in the above mentioned report. We refer to Annex A and B for the ranking results of these cities on the basis of the above mentioned principles.

4. Methodology: the SOM as a Decision Support Toolbox[2]

The approach we adopt there to visualize the world cities database described in Section 3 and to explore hidden patterns is fundamentally based on one algorithm: the self-organising map (Kohonen, 2001). The self-organizing map (or simply SOM from now on) is an unsupervised computational neural network, which means it is a technique that relies on a set of nodes or neurons interconnected to each other, hence 'neural network', and in which the input observations are not categorized *a priori* but in which rather the structure is unknown, hence 'unsupervised'. It was developed in the context of the study of the spatial organization of brain functions (Kohonen and Honkela, 2007), where the interest was in obtaining a methodology that allowed to explore highly dimensional very large datasets. There was thus a need to perform data reduction on two fronts: the number of dimensions ('projection') and the number of observations ('quantization'), preserving at the same time the structure and useful information in the dataset. Over the years since it was created, the SOM has been applied in a wide range of fields1, although its impact in the social sciences was, up until very recently, limited (some exceptions include: Skupin and Hagelman, 2005; Spielman and Thill, 2008; Yan and Thill, 2009; Kourtit et al., 2011; Arribas-Bel et al., 2011). However, nowadays we are witnessing the appearance of large and highly dimensional data sets about socio-economic characteristics and human phenomena. Such an increase in the amount and complexity of data brings a need for a set of tools that allows to explore the structures and to uncover hidden patterns. There is also a need for tools that enable the visualization and present these complex entities in an understandable way. This is particularly true at a policy support level, where the understanding of such relationships is crucial for appropriate decision making. In this context, the SOM is one such tools that can enhance knowledge assimilation and thus help close the gap between data and informed decisions.

Although 'SOM' originally refers to the algorithm at work, the term is also used to describe the visual maps created by this technique. In its basic version (the one we will be using in this study), the output of a SOM is portrayed by a network of hexagonal polygons that represent the different neurons, connected to each other by topological relationships

[2] This section only gives guidance in how to interpret the output of a SOM; to facilitate reading and understanding, it avoids the underpinnings as well as mathematical notation. For a thorough explanation, the reader is referred to Kohonen (2001).

(edge-sharing neurons). The properties of the algorithm lead this map to represent the statistical properties of the original dataset used to create it; in effect, the output network can be seen as a sort of statistical space or virtual topology in which the spatial configuration is closely linked to the statistical properties of the dataset. In this context, statistical dissimilarity is translated into spatial distance, with close-by regions in the SOM representing similar statistical properties in the original database and vice versa. This feature is obtained due to the learning nature of the algorithm which allows the network to evolve over the training stage of the algorithm and to capture the information contained in the input dataset, compress it into the output map, and present it in an understandable fashion.

A *trained* network is ready for analysis. There are several ways to study a SOM and obtain useful information from it; in this paper we basically rely on two main devices: the component planes and the best matching units (or BMUs hereafter). The former are based on the idea of showing the distribution of the variables used for the algorithm on top of the SOM. Each neuron is assigned a vector of as many dimensions as variables used to create the map, and these values can be visualized one variable at a time through a gradient of colors to explore the global patterns as well as to characterize different regions of the SOM. When we use the component planes, not only are we able to say that neighboring neurons in one region of the SOM are similar, but we are also able to characterize them in terms of the variables used in the first place for the algorithm.

The BMUs are the common way to link the original observations (cities in this case) to the output network. Fundamentally, for each observation in the original dataset, its BMU is defined as the most similar neuron in the SOM. They are very useful because they provide a tool to locate the original observation onto the map, and thus to visualize two important aspects: first, what region of the SOM they are in; and second, how their location relates to that of the other observations. This is particularly important if we keep in mind that, in a SOM, spatial distance translates into statistical dissimilarity. In this paper we will be using the BMUs in two particular contexts: a dynamic one and a static one. In the latter one, each BMU represents one city, using always data for only one year; in this case, the analyst can see how the cities are structured over the virtual space created by the SOM, and which cities cluster around which ones. An extension to this approach we will use as well consists of mapping with a color gradient the values from another variable we are interested in, allowing to see whether significant patterns arise in the distribution of this value over the SOM. Alternatively, we can use data from different years as input for the SOM; in this case, each observation represents one city at one point in time. We can then divide observations by year and see whether there patterns that emerge (are all the observations for each year in the same area of the SOM?); and we can also follow the cities over the years, by drawing lines (trajectories) between their location at each point in time. This dynamic analysis allows to see how the dataset evolves over time, and what are the main changes that occur over the period. The above pedagogical introduction should be sufficient to offer an understanding of the results from a SOM analysis of our GPCI cities data base.

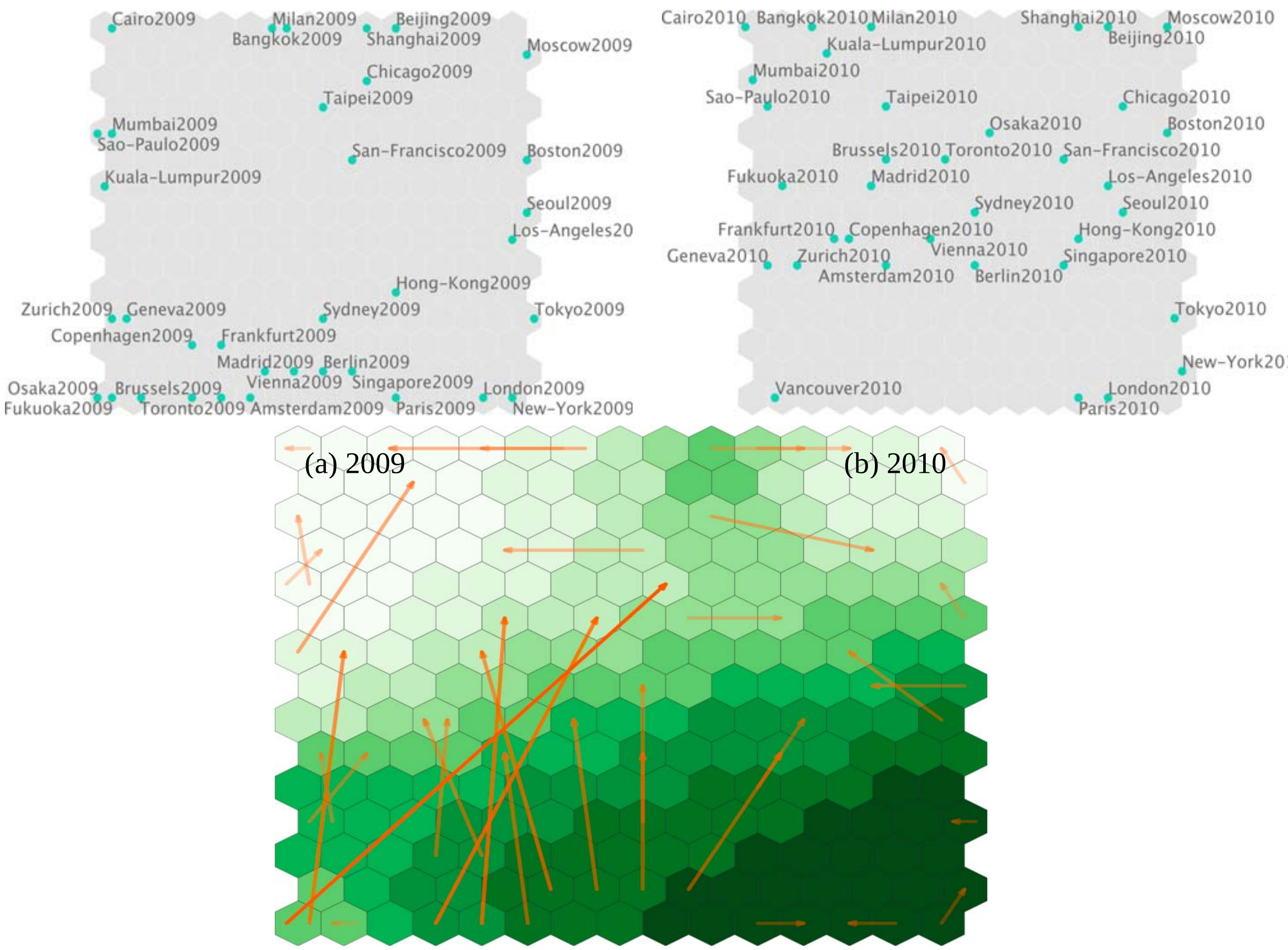
5. Patterns and Dynamics of World Cities 2009-2010

The above SOM approach has been used to arrive at a better understanding of the structure and short-term evaluation of the information contained in our data base. In the first place, we will consider the evolution of the cities in terms of the global score over the year from 2009 to 2010. For that purpose, we run a SOM using data from both years in a pooled fashion, where each observation is one city at one point in time, and its attributes are the scores in each of the functions. This approach creates a statistical space based on the information from both years, allowing us to map the cities in each period as separate points and to analyze their change. Such evolution from 2009 to 2010 is translated into a movement from one location in the SOM to another one, which we call the trajectory of the city.

Figure 1 shows the three components of the trajectories: the cities' location in 2009 (a); the analogue in 2010 (b); as well as a visualization of the movement (c). If we focus first on 1 (a) and 1 (b), there is already a clear pattern: a mass of cities that in 2009 were located along the bottom edge moves up to the center of the SOM, filling the empty space that appears in this area in 2009 and creating a new empty area that stretches over most of the bottom part. This displacement has the effect of isolating the top four cities (New York, London, Tokyo and Paris), which remain in the same bottom-right corner, experiencing only minimal changes of location.

Figure 1 (c) complements the story sketched in (a) and (b). The image shows the same network as before, where the trajectories of the cities have been plotted with arrows, varying the transparency depending on the length of the arrow to highlight the greatest changes. In addition, since the global score is the sum of the scores in the six basic functions in our database, we are also able to calculate such an index for each of the neurons in the SOM by summing across dimensions; this is displayed as well using a gradient of nine quantiles from white (lowest values) to dark green (highest ones). The combination of both allows us to visualize intuitively what the change from 2009 to 2010 has meant for the cities: the movement towards the center we saw in 1 (a) and (b) translates into a decrease in the global scores of the cities that re-locate. On the contrary, as we mentioned before, the top four cities barely change and remain in the area with highest scores, creating a gap between them and the rest of the sample. Last, for the cities in the upper part (those with lowest indices), the period also brought a general decrease in the global performance.

This application of the SOM to study the dynamics of the index allows us to display the information from the global results of the GPCI in a very intuitive way and enhances the understanding of the main changes that have occurred from one year to the following: an *isolation* of the top four cities that have not only remained as the highest performers but also widened the gap with the rest. This phenomenon, that was already stated in the original GPCI report, is presented here in a much more easy-to-visualize way that enhances further exploration of the results.



(a) 2009 (b) 2010

(c) Trajectories

Figure 1: Evolution of GPCI cities from 2009 to 2010

6. A Further Analysis of the GPCI Database 2010

While in Section 5 we have analyzed where the cities arrived to 2010 from, in this section we delve into the particularities of 2010. Figure 2 displays a trained SOM obtained only from this year where the cities have been mapped, as usual, according to their BMU. In the same fashion as Figure 2(c), the global index has been mapped onto the surface of the SOM by adding up each neuron's values for all the functions and using then a gradient from white (lowest scores) to dark blue (highest ones). It is interesting to note that the distribution of the global index over the SOM is almost that of a perfect gradient where the lowest values locate in the bottom-left corner and it increases gradually as one moves up and right.

The figure represents thus the statistical topology of the GPCI database in 2010 (for the GPCI results of 2009, we refer to Annex C) and, in a way, it can be seen as the two-dimensional version of the rank provided in the report. If we think of it as a line from the cities with lowest scores (Cairo, Mumbai, Sao Paulo) to the best performers (New York, London, Paris or Tokyo), the map in Figure 2 *unfolds* those results into an extra dimension that allows to fit in more patterns and information than the original linear representation. The figure allows to study the rank, as one can see through the color scheme the performance of one city compared to the others; moreover, and what is more interesting, the map allows further investigation and the uncovering of patterns that would be difficult, if not impossible, to identify with only the original results. As an example, the mapping of the cities in two dimensions allows to relate similar cities that might look further from each other in the rank list. If we focus on the diagonal band that stretches from the upper-left to the bottom-right zones of the SOM, we can see a group of cities that occupy the middle part of the list. However, what cannot be seen in the rank is that there are clear regional patterns: western European cities tend to locate in the upper-left part, while North-American and Asian cities tend to be found on the central and the lower right parts.

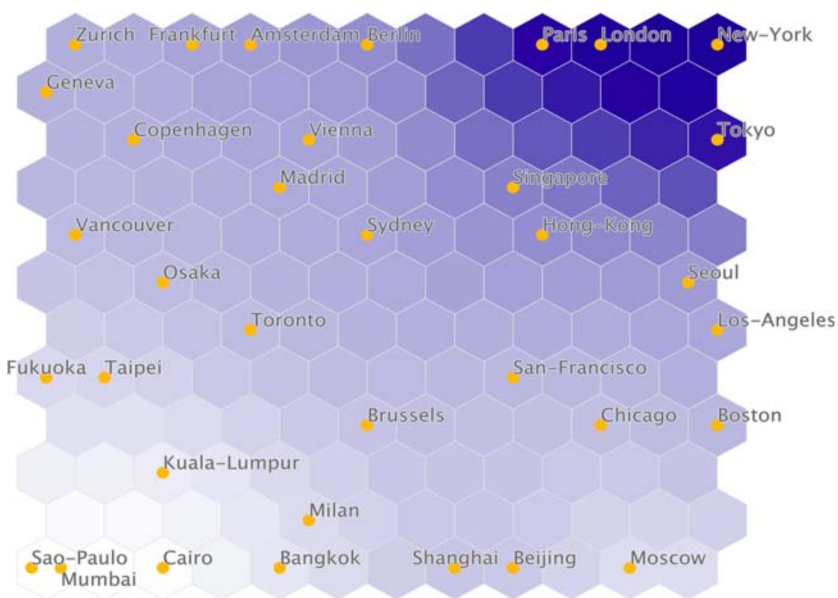


Figure 2: GPCI results 2010

In order to better understand what these regional patterns may mean, we need to know what being located in different parts of the SOM implies. We use an additional tool for that purpose: the component planes. As explained in Section 4, the component planes are a representation of the distribution of the values of one of the dimensions used to run the SOM algorithm. Since in this case we have used the six function-specific indices to obtain Figure 2, we can analyze the distribution of each of them in the SOM and characterize different areas based on their scores in one or another variable.

Figure 3 shows the component planes for each of the six function-specific variables in which the values are displayed on a gradient from white (lowest) to dark blue (highest). This tool allows to obtain different profiles for the regions of the SOM, discover in which aspects they are stronger or weaker and, ultimately, to understand what drives the final GPCI score. For instance, it is easy to see that the upper-right corner, the one where the top four cities are, excels in '*economy*', '*R&D*', '*cultural interaction*' and '*accessibility*'; or that the bottom-left region performs poorly in most of the functions, with the exception of '*livability*' and '*environment*'. By extension, the planes are also very useful when compared to the location of the cities (Figure 2): we can see how emerging cities like Beijing or Shanghai have very high scores on economy, but poor on environment; or how other cities like Sydney obtain their final score based on a balanced profile of medium scores in all the dimensions.

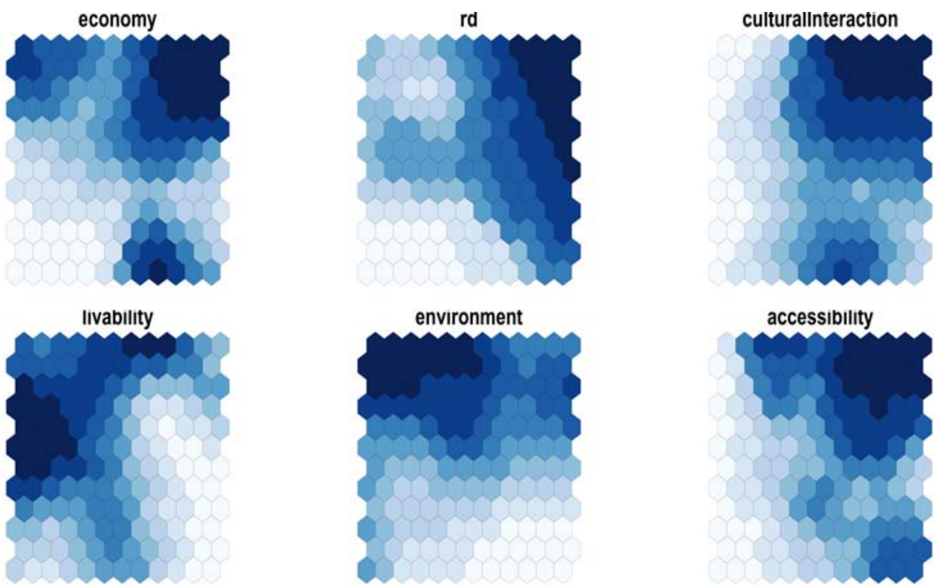


Figure 3: GPCI 2010-Planes

The component planes also allow us to profile the regional patterns we pointed out before. The Western European cities that cluster in the upper-left part (Zurich, Frankfurt, Amsterdam, Copenhagen) have a relatively high economic performance and livability, mixed accessibility and a relatively poor R&D and cultural interaction; on the contrary, North-American cities (Los Angeles, San Francisco, Chicago, Boston) and some Asian ones (Seoul, Hong Kong or Singapore) obtain similar final results thanks to a high score in R&D and cultural interaction, but appear to perform poorly in livability and environment.

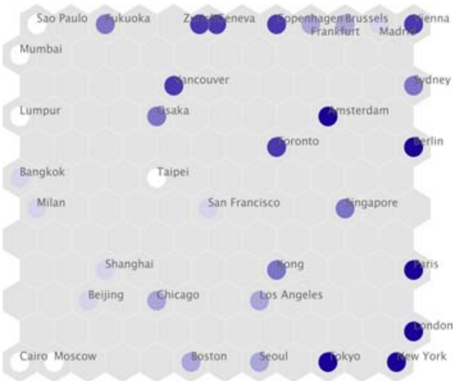
7. **Actor-Specific SOM Analysis**

In the last part of the analysis, we consider the scores given to all cities by five types of different actors (denoted in an ideal-typical manner as ‘*artist*’, ‘*manager*’, ‘*researcher*’, ‘*resident*’ and ‘*visitor*’) and combine them with the SOM framework of this paper. Our methodology is based primarily on the following approach: we take the value scores from the actors and convert them into a color gradient scheme that we use to replace the usual dots of the cities in the SOM. By doing this, we can obtain the general pattern of the actor's view on the surface and analyze what are the aspects of a city each actor values most. Figure 4 shows the results of this methodology.

(a) Artist

(b) Manager

(c) Researcher



(d) Resident

(e) Visitor

Figure 4: five types of different actors

The first interesting aspect to note is the persistent high impression all the actors have of the top four cities: in all cases, they are always in the top tier. When we focus on each class of actor individually, other patterns arise. In the case of the *artist* (4a), Chinese and some European cities (Amsterdam, Berlin) are the preferred ones, in addition to some of the ones which overall perform worse (Cairo, Kuala Lumpur). Among the least preferred ones we find some of the North-American (Chicago, Boston), South-East Asian (Singapore, Hong Kong) and the Swiss ones. Since the distribution is so scattered, it is hard to identify any particular function that is most valued. The pattern of *managers* (4b) is much clearer: cities highly appreciated by this actor are always those with a high economic performance. In this category, we can include: Beijing and Shanghai, Singapore and Hong Kong as well as some of the Europeans (Zurich, Geneva, Copenhagen). A similar case is that of the *researcher*: cities with a good economic performance are well seen by this actor, who particularly values, amongst others, those with high scores in R&D (Seoul, Los Angeles); on the other extreme, there is the case of Madrid for which, although its economic performance is good, its low R&D translates into a very low appreciation by the researcher. Finally, the views of the *resident* (4d) and the *visitor* (4e) in general are similar, although with a few exceptions: both actors perceive positively cities in the upper-left part, which are all western, and mostly European; however, there are also important differences like San Francisco or Boston, which are highly rated by residents but very poorly by visitors.

8. Concluding Remarks

In our modern knowledge society and competitive economy, creative strategies, governance and management are increasingly required for enhancing the global cities' attractiveness in order to become really competitive in an open world with so many world cities in different parts of our planet. Their attractiveness – in terms of socio-economic power performance of major global cities – is increasingly regarded as a key factor to maintain and strengthen their developmental potential in the global competition and in knowledge-based economies.

Many major global cities and regions host a wealth of socio-economic attractions and new and innovative activities and facilities and have to compete for the favours of various stakeholders (e.g., talent, business, tourists, investment), both domestically and internationally.

To obtain an idea where these metropolitan areas stand and whether various stakeholders should continue to invest in these major global cities, specific marketing tools – e.g., benchmarking analysis and supporting vehicles and tools – have to be used which could help to provide and enhance the attractiveness of these cities.

In the context of comparing the attractiveness of major global cities, our empirical study has mapped out the relative disparities among a preselected set of major global cities by developing a benchmark analysis of these cities, on the basis of a recently completed comparative study (GPCI-2010) on 69 individual indicators of a city's socio-economic 'power' performance across six main dimensions in terms of their 'pluriformity' characteristics, viz. 'Economy', 'Research & Development', 'Cultural Interaction', 'Liveability', 'Ecology & Natural Environment', and 'Accessibility'. Furthermore, our study has also identified future challenges and opportunities for global city sustainability policy in an urbanizing world. And finally, also an actor-oriented analysis of the various performance items of these cities is given. The analytical tool employed to highlight the features of global cities and to encourage various stakeholders to reconsider the attractiveness of these major cities, as well as to better understand the relative position of 35 major cities in our world for establishing urban strategies – or scenarios – in order to improve the weaknesses identified, is from a topological perspective based on Self-Organizing Maps (SOMs).

We propose the SOM algorithm as a helpful method to study socio-economic multi-dimensional data as well as a useful tool to present complex relationships and patterns to policy makers in a visual way that enhances understanding and knowledge creation. The GPCI dataset is analyzed from three main perspectives: dynamic, function-specific and actor-based.

In the first place, we visualize results from both 2009 and 2010 in order to map out the evolution over the statistical space created by the SOM results that, over this period, there has been an isolation of the top four cities, while the vast majority of cities in the middle part of the ranking have maintained similar distances among themselves.

In our function-specific analysis, we consider the results for 2010 in more depth; we overlay the original index on top of the visualization to compare both methodologies and carry out a detailed analysis of the map created, translating the location of the cities in the SOM into different profiles, and identifying the main strengths and weaknesses of the cities.

In the last part, we use the 2010 results to compare them to the actor-based rankings; this exercise allows us to identify what are the aspects that different actors value most and to see how these views compare to the main function-specific ranking.

The main contribution of this paper lies in the enhanced visualization offered by the SOM of the original GPCI results. Although the input data employed in this study are virtually the same, the properties of the new method used allow for a much more appealing presentation that in turn facilitates the analysis and detection of patterns. This leads not only to a confirmation of the main original conclusions from the GPCI study presented in a much more intuitive way, but also to new insights into the dataset such as, for instance, the regional patterns that appear in the grouping of the cities, or the different value put on each dimension depending on the actor. In the light of these characteristics of the SOM technique, we conclude by hoping that more studies in the social sciences will include in the future this kind of approaches when analyzing multi-dimensional datasets, particularly when they are geared towards future issues that bother policy-makers and need decision support.

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ANNEX A. GPCI-2010 Function-specific Ranking

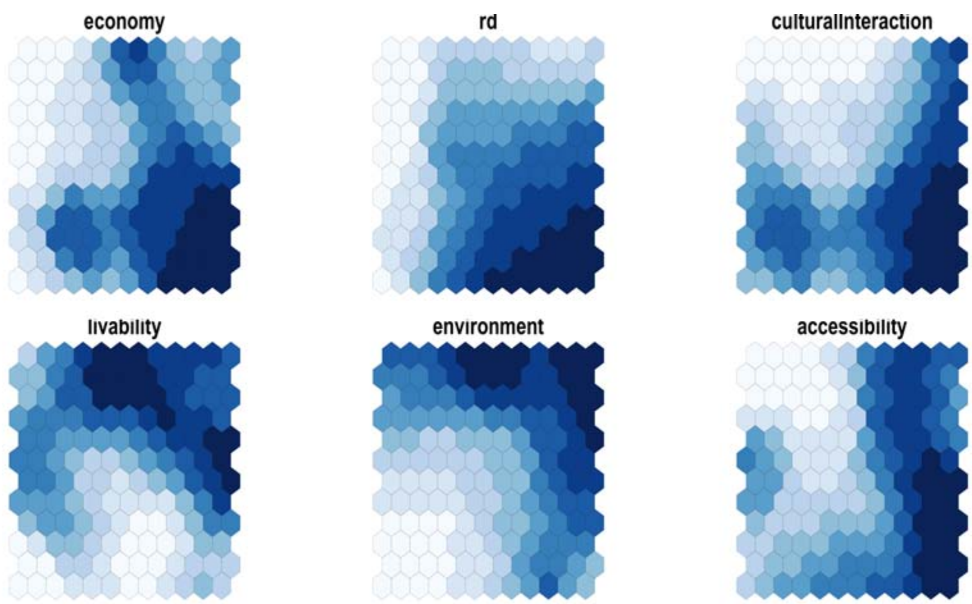
Rank	Total Score				Economy				R&D				CulturalInteraction				Livability				Environment				Accessibility				Rank
	2010		2009		2010		2009		2010		2009		2010		2009		2010		2009		2010		2009		2010		2009		
	City	Score	Score	Rank	City	Score	Score	Rank	City	Score	Score	Rank	City	Score	Score	Rank	City	Score	Score	Rank	City	Score	Score	Rank	City	Score	Score	Rank	
1	New York	321.2	330.4	1	Tokyo	58.3	54.7	2	New York	76.4	63.0	1	London	60.6	58.2	1	Vancouver	60.7	65.9	3	Zurich	71.4	71.7	2	Paris	57.9	59.3	1	1
2	London	313.3	322.3	2	New York	58.2	63.6	1	Tokyo	56.4	60.3	2	Paris	51.3	47.0	3	Paris	55.6	67.2	1	Geneva	70.5	71.8	1	London	56.0	51.8	2	2
3	Paris	304.1	317.8	3	London	50.5	52.1	3	London	44.1	51.2	3	New York	50.6	54.1	2	Osaka	51.6	62.4	15	Berlin	66.8	66.1	5	New York	47.8	42.9	4	3
4	Tokyo	299.0	305.6	4	Beijing	49.1	41.5	7	Boston	43.8	40.7	6	Tokyo	32.0	28.9	6	Fukuoka	49.8	63.3	11	Frankfurt	66.5	66.0	6	Singapore	42.1	41.2	6	4
5	Singapore	243.5	274.4	5	Hong Kong	44.4	43.2	4	Paris	40.3	39.5	7	Singapore	31.0	29.7	5	Milan	49.4	61.6	18	Tokyo	65.6	67.0	4	Amsterdarr	41.0	42.9	3	5
6	Berlin	232.9	259.3	6	Singapore	43.0	42.8	5	Seoul	40.2	49.7	4	Beijing	29.1	28.5	8	Berlin	48.7	67.0	2	Amsterdarr	65.3	63.4	10	Tokyo	39.1	34.3	11	6
7	Amsterdarr	230.9	250.5	8	Paris	42.9	42.5	6	Los Angele	38.7	41.3	5	Berlin	28.2	30.8	4	Madrid	48.6	62.6	14	Vienna	64.3	69.6	3	Frankfurt	38.5	42.3	5	7
8	Seoul	228.1	241.1	12	Shanghai	42.3	41.4	8	Hong Kong	30.5	34.9	9	Los Angele	27.1	26.4	11	Amsterdarr	48.2	63.3	10	Sao Paulo	63.0	64.5	8	Hong Kong	38.0	30.9	21	8
9	Hong Kong	224.3	242.5	10	Geneva	42.2	39.4	11	Singapore	29.7	36.7	8	Hong Kong	25.6	27.9	9	Tokyo	47.6	60.4	19	Copenhage	62.7	61.1	13	Moscow	36.5	36.3	9	9
10	Sydney	218.5	237.3	14	Zurich	41.3	40.7	10	Chicago	28.9	27.6	12	Vienna	24.9	28.7	7	Vienna	47.5	64.9	6	Madrid	60.6	65.7	7	Seoul	36.1	36.6	8	10
11	Vienna	217.7	255.1	7	Copenhage	41.1	40.9	9	San Franci:	28.1	27.5	13	Shanghai	23.9	25.4	12	Geneva	47.4	64.2	7	Sydney	60.4	64.1	9	Madrid	35.4	38.2	7	11
12	Zurich	215.2	242.5	9	Amsterdarr	40.1	36.1	18	Osaka	24.1	26.4	15	Sydney	23.2	27.9	10	Brussels	46.9	63.9	8	Singapore	59.0	61.8	12	Brussels	34.4	34.2	12	12
13	Frankfurt	213.1	232.9	16	Frankfurt	38.5	31.7	24	Berlin	22.7	33.2	10	Bangkok	22.6	20.5	16	Copenhage	46.7	63.4	9	London	57.8	59.8	16	Boston	33.5	33.7	14	13
14	Los Angele	210.4	240.0	13	Sydney	37.8	36.9	16	Sydney	22.2	23.6	18	Madrid	21.4	25.3	13	Toronto	46.4	64.9	5	Fukuoka	57.6	59.7	17	Chicago	32.8	31.5	19	14
15	Madrid	209.0	242.5	11	Vienna	36.7	38.3	12	Toronto	20.1	25.7	17	Brussels	21.4	20.4	17	Shanghai	46.4	62.9	13	Vancouver	56.4	59.4	18	Berlin	32.6	30.4	22	15
16	Vancouver	207.9	219.1	23	Seoul	36.4	33.9	22	Moscow	19.6	27.5	14	Seoul	20.9	20.7	15	Zurich	45.7	65.1	4	Paris	56.2	62.3	11	Shanghai	31.6	27.9	26	16
17	Copenhage	206.6	231.7	17	Toronto	35.8	38.1	13	Zurich	19.2	22.5	19	Chicago	20.8	23.1	14	Taipei	45.4	53.5	28	Seoul	55.8	54.1	24	Copenhage	31.3	36.1	10	17
18	Osaka	205.9	215.1	25	Moscow	35.1	28.2	27	Amsterdarr	18.5	25.7	16	Milan	20.2	19.1	18	Frankfurt	45.2	62.2	16	Los Angele	55.5	57.1	20	Beijing	30.9	29.8	23	18
19	Boston	205.4	226.2	20	Vancouver	34.6	34.5	21	Vancouver	17.8	20.2	21	Amsterdarr	17.9	19.1	19	Sydney	45.2	58.3	23	San Franci:	54.8	56.5	21	Toronto	30.8	33.9	13	19
20	Geneva	204.3	229.7	19	Osaka	34.0	31.3	26	Geneva	17.0	19.9	23	Toronto	16.9	17.8	21	London	44.3	49.1	33	Kuala Lump	54.2	60.5	15	Milan	30.8	32.9	15	20
21	Brussels	203.0	229.9	18	San Franci:	33.9	36.2	17	Taipei	16.7	27.9	11	San Franci:	16.3	15.9	23	Mumbai	42.7	54.8	27	Hong Kong	53.1	55.5	22	Kuala Lump	30.5	32.1	18	21
22	San Franci:	202.4	218.1	24	Berlin	33.8	31.9	23	Vienna	15.6	21.1	20	Moscow	15.7	16.7	22	Sao Paulo	40.2	55.5	25	Osaka	52.8	58.7	19	Osaka	30.5	23.5	32	22
23	Toronto	202.2	234.6	15	Boston	33.2	34.5	20	Fukuoka	14.8	19.8	24	Kuala Lump	14.0	15.7	24	Beijing	40.1	58.5	22	Brussels	52.7	60.8	14	Sydney	29.7	26.6	29	23
24	Beijing	198.9	211.4	26	Brussels	32.8	31.4	25	Brussels	14.7	19.2	25	Boston	13.1	14.0	25	San Franci:	40.0	52.8	29	Toronto	52.2	54.3	23	Zurich	29.6	31.5	20	24
25	Chicago	197.0	221.1	22	Madrid	32.1	36.1	19	Frankfurt	13.8	18.2	26	Osaka	12.9	12.9	27	Bangkok	39.4	59.8	20	New York	51.2	47.7	30	San Franci:	29.3	29.1	24	25
26	Shanghai	196.5	224.1	21	Chicago	31.5	37.8	14	Copenhage	13.5	17.8	28	Vancouver	12.4	13.7	26	Seoul	38.8	46.2	34	Mumbai	51.1	53.6	25	Cairo	29.3	22.5	33	26
27	Milan	184.4	203.5	28	Los Angele	31.3	37.4	15	Beijing	13.5	18.2	27	Cairo	11.9	18.4	20	Kuala Lump	38.7	62.9	12	Taipei	48.5	48.8	28	Bangkok	29.1	32.1	17	27
28	Fukuoka	182.9	196.5	30	Taipei	30.2	28.0	28	Shanghai	11.5	19.9	22	Copenhage	11.2	12.4	28	Singapore	38.6	62.2	17	Bangkok	47.5	53.3	26	Vienna	28.7	32.6	16	28
29	Taipei	176.7	195.9	31	Kuala Lump	28.7	25.1	30	Madrid	10.9	14.6	29	Frankfurt	10.5	12.3	29	New York	37.0	59.1	21	Milan	46.9	51.3	27	Taipei	28.4	28.8	25	29
30	Kuala Lump	170.4	204.1	27	Fukuoka	28.1	23.9	31	Milan	9.5	12.8	30	Sao Paulo	9.9	11.8	30	Chicago	36.9	56.0	24	Boston	46.6	48.4	29	Fukuoka	28.3	24.9	31	30
31	Bangkok	169.5	199.1	29	Milan	27.5	25.8	29	Bangkok	6.9	11.1	31	Mumbai	9.4	10.2	32	Boston	35.2	55.0	26	Chicago	46.0	45.2	32	Vancouver	25.9	25.5	30	31
32	Moscow	163.7	179.5	32	Bangkok	24.0	22.2	32	Kuala Lump	4.4	7.8	34	Zurich	8.0	11.0	31	Los Angele	34.3	51.0	30	Cairo	42.5	35.4	33	Los Angele	23.5	26.8	28	32
33	Sao Paulo	158.8	177.7	33	Sao Paulo	24.0	18.5	33	Mumbai	3.9	8.4	33	Taipei	7.3	9.0	33	Moscow	34.0	49.4	32	Shanghai	40.8	46.5	31	Geneva	22.2	27.5	27	33
34	Mumbai	145.2	165.5	34	Mumbai	20.7	18.3	34	Sao Paulo	3.0	9.2	32	Geneva	5.0	7.0	34	Cairo	33.0	35.5	35	Beijing	36.3	35.0	34	Sao Paulo	18.8	18.1	35	34
35	Cairo	137.6	132.2	35	Cairo	19.6	18.0	35	Cairo	1.3	2.3	35	Fukuoka	4.3	4.7	35	Hong Kong	32.7	50.1	31	Moscow	22.8	21.3	35	Mumbai	17.4	20.1	34	35

ANNEX B. GPCI-2010 Actor-specific Ranking

Rank	Manager				Researcher				Artist				Visitor				Resident				Rank
	2010		2009		2010		2009		2010		2009		2010		2009		2010		2009		
	City	Score	Score	Rank	City	Score	Score	Rank	City	Score	Score	Rank	City	Score	Score	Rank	City	Score	Score	Rank	
1	New York	34.4	55.2	2	New York	37.0	62.6	1	Paris	24.8	58.9	2	London	31.4	57.7	2	Paris	36.2	61.4	2	1
2	Shanghai	34.1	48.3	5	Tokyo	31.3	56.8	3	Tokyo	18.4	46.9	5	New York	28.7	59.4	1	Tokyo	31.5	60.7	4	2
3	Beijing	33.4	46.1	8	Paris	24.5	51.4	4	London	17.8	48.8	4	Beijing	27.9	49.0	4	Zurich	31.3	57.6	7	3
4	Singapore	33.4	53.8	3	Boston	22.5	42.7	7	New York	17.1	60.3	1	Singapore	25.1	43.6	9	Frankfurt	31.2	51.7	21	4
5	Hong Kong	32.8	48.6	4	London	22.2	57.7	2	Berlin	14.0	48.9	3	Berlin	24.3	45.5	8	London	30.4	59.0	5	5
6	London	31.2	55.2	1	Seoul	21.5	44.4	5	Beijing	13.7	29.3	26	Paris	24.2	54.8	3	Brussels	29.0	52.2	19	6
7	Geneva	28.3	44.5	10	San Franci	17.0	36.2	12	Osaka	11.6	29.1	27	Shanghai	23.8	46.9	5	Geneva	28.4	55.0	12	7
8	Zurich	27.4	44.6	9	Los Angele	16.4	43.4	6	Kuala Lump	11.4	32.4	16	Tokyo	23.7	46.0	7	Boston	28.2	52.1	20	8
9	Tokyo	26.6	46.5	7	Hong Kong	16.1	36.4	11	Amsterdam	11.1	37.6	9	Hong Kong	23.4	42.3	10	San Franci	27.7	49.5	26	9
10	Paris	26.1	47.5	6	Zurich	13.8	32.4	16	Cairo	11.1	18.9	35	Vienna	21.7	46.1	6	New York	27.5	64.5	1	10
11	Seoul	25.8	40.3	18	Singapore	13.6	42.6	8	Los Angele	11.0	38.9	8	Seoul	21.3	38.8	16	Milan	26.9	45.4	28	11
12	Copenhage	25.7	43.7	13	Osaka	13.6	29.7	21	Shanghai	10.9	32.9	14	Brussels	21.3	40.0	14	Hong Kong	26.7	54.1	13	12
13	Vancouver	25.7	41.8	16	Sydney	12.9	35.8	13	Madrid	10.9	35.5	10	Amsterdam	19.9	39.8	15	Vancouver	26.6	56.0	10	13
14	Vienna	25.4	44.0	11	Beijing	12.8	26.1	27	Brussels	10.8	33.5	12	Osaka	19.8	34.8	24	Beijing	25.9	48.4	27	14
15	Amsterdam	25.1	43.9	12	Chicago	12.8	37.0	10	Sydney	10.7	29.6	25	Toronto	19.7	38.7	17	Amsterdam	25.8	57.9	6	15
16	Toronto	24.5	43.2	14	Copenhage	12.6	32.2	17	Frankfurt	10.5	31.2	20	Madrid	19.6	41.3	11	Copenhage	25.3	56.5	9	16
17	Madrid	24.4	41.8	15	Moscow	12.3	30.4	19	Moscow	10.5	30.5	24	Sydney	19.0	37.4	18	Taipei	25.2	43.6	30	17
18	Moscow	23.7	30.9	32	Amsterdam	11.3	34.9	14	San Franci	10.4	32.9	15	Vancouver	18.3	34.5	25	Seoul	25.2	50.6	23	18
19	Kuala Lump	23.7	36.9	25	Geneva	11.0	31.6	18	Bangkok	10.4	31.5	19	Bangkok	18.1	40.3	13	Berlin	25.0	60.9	3	19
20	Taipei	23.4	35.7	27	Vancouver	10.9	27.2	23	Mumbai	10.3	23.1	34	Geneva	18.1	32.2	31	Sydney	24.8	54.0	15	20
21	Frankfurt	23.1	38.5	24	Berlin	9.4	39.6	9	Vancouver	10.1	31.2	21	Zurich	17.9	34.2	27	Vienna	24.6	57.0	8	21
22	Chicago	22.7	40.4	17	Toronto	9.4	30.0	20	Vienna	10.1	39.5	7	Copenhage	17.3	35.0	23	Osaka	24.6	54.0	14	22
23	Boston	22.5	39.8	20	Vienna	9.2	33.9	15	Taipei	10.0	28.1	29	Frankfurt	17.0	36.4	21	Fukuoka	24.2	53.1	16	23
24	Brussels	22.2	39.2	23	Taipei	8.7	26.3	25	Milan	9.9	33.4	13	Taipei	16.9	33.8	29	Toronto	21.9	55.8	11	24
25	Berlin	21.4	39.5	21	Shanghai	8.4	27.1	24	Fukuoka	9.7	26.7	30	Milan	16.9	36.8	20	Shanghai	21.6	50.6	24	25
26	Sydney	20.7	39.9	19	Fukuoka	8.1	26.3	26	Seoul	9.4	25.8	31	Cairo	16.8	35.1	22	Madrid	21.1	50.0	25	26
27	Los Angele	20.6	39.4	22	Brussels	7.3	28.7	22	Sao Paulo	9.4	25.5	32	Los Angele	16.3	34.0	28	Los Angele	20.6	50.8	22	27
28	Osaka	20.1	35.3	28	Bangkok	7.2	23.8	30	Toronto	9.2	35.0	11	Fukuoka	16.2	28.5	34	Chicago	19.9	52.6	18	28
29	Bangkok	20.0	32.7	29	Frankfurt	7.0	25.5	28	Copenhage	9.2	31.9	17	Chicago	15.8	37.2	19	Singapore	17.7	52.8	17	29
30	San Franci	19.1	36.3	26	Milan	6.4	22.6	31	Chicago	8.6	39.5	6	Kuala Lump	13.6	40.5	12	Moscow	17.3	34.1	34	30
31	Fukuoka	18.5	32.1	30	Kuala Lump	5.8	21.3	32	Geneva	8.4	28.3	28	Boston	13.3	34.4	26	Cairo	15.5	27.2	35	31
32	Mumbai	18.0	27.0	33	Mumbai	4.9	18.9	34	Zurich	7.8	31.0	22	San Franci	12.2	32.2	30	Bangkok	15.2	45.1	29	32
33	Cairo	17.7	26.7	34	Madrid	4.8	25.4	29	Boston	6.7	30.9	23	Mumbai	11.6	28.9	33	Mumbai	14.4	39.2	32	33
34	Milan	16.4	31.4	31	Sao Paulo	3.8	19.0	33	Singapore	6.4	31.9	18	Moscow	10.3	30.4	32	Kuala Lump	14.1	39.7	31	34
35	Sao Paulo	15.8	22.5	35	Cairo	2.7	11.9	35	Hong Kong	4.6	24.4	33	Sao Paulo	8.3	24.1	35	Sao Paulo	13.2	37.4	33	35

ANNEX C. SOM Results for 2009

Figure C 1: GPCI results 2009



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